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ABSTRACT

This selective bibliography of recent publications by Rand researchers in the Information Processing Systems research program includes only those papers concerned with the broad range of topics in cognitive science. These topics include the modeling of complex human behavior, the construction of intelligent computer systems, and the representation of knowledge in human and computer memories; the research draws upon the disciplines of cognitive psychology, educational psychology, computer science, artificial intelligence, and linguistics. The first of two sections provides abstracts for papers published between April 1978 and April 1979. The second section contains a list of titles published prior to April 1978 which are abstracted in Rand Paper P-5950. Titles are arranged alphabetically with topic and author indexes, and information is provided for obtaining reprints of the listed publications. (Author/RAA)

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SELECTED RESEARCH PUBLICATIONS IN COGNITIVE SCIENCE

BY RAND STAFF: 1978-1979

R.H. Anderson, J. Burge, W.S. Faught, B. Hayes-Roth,
F. Hayes-Roth, P. Klahr, S. Rosenschein,
P. Thorndyke, D. Waterman, R. Wesson

July 1979

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PREFACE

The bibliography presented on the following pages is a compilation of recent publications by some of the Rand researchers in the Information Processing Systems research program. The bibliography is selective, comprising only those papers concerned with the broad range of topics in Cognitive Science. These topics include the modeling of complex human behaviors, the construction of intelligent computer systems, and the representation of knowledge in human and computer memories. The research draws upon the disciplines of cognitive psychology, educational psychology, computer science, artificial intelligence, and linguistics.

The bibliography is organized into two sections. The first section contains abstracts for papers published between April 1978 and April 1979. The second section contains a list of titles published prior to April 1978. Rand Paper P-5950 contains the abstracts for these earlier papers.

The titles are organized alphabetically, with topic and author indexes following the list of publications. The Rand researchers represented in this bibliography are Robert Anderson, John Burge, William Faught, Barbara Hayes-Roth, Frederick Hayes-Roth, Philip Klahr, Stan Rosenschein, Perry Thorndyke, Don Waterman, and Robert Wesson. Requests for reprints of Rand publications may be addressed to the Rand Publications Department, 1700 Main Street, Santa Monica, California 90406. Requests for reprints of journal articles or book chapters should be addressed directly to the author.

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RESEARCH IN COGNITIVE SCIENCE BY RAND STAFF: 1978-1979

80. Anderson, R., and Shapiro, N. Design considerations for a computer-based interactive map display system. Rand Report R-2382-ARPA, 1979.

A discussion of the key features of an interactive map display system that affect both the usefulness of the system and the design and architecture of its hardware and software. Recent developments in computer graphics offer the possibility of creating interactive map display systems having many of the advantages of traditional paper maps, but significant additional advantages as well. From a set of informal experiments, we have concluded that the design of electronic maps should not mimic that of paper maps; they are a fundamentally different medium. A number of design guidelines are presented, along with the rationale for each. In addition, the report describes a five-dimensional "design space" that we feel is useful for elucidating design choices for map display systems.

81. Dent, C., and Thorndyke, P. Children's use of schemata in learning narrative discourse. Rand Paper P-6318, 1979.

Two experiments investigated children's use of schemata in learning narrative discourse. Six-, eight-, and ten-year-olds listened to and then were tested on memory for two simple narrative stories. The structure of both stories could be represented as a hierarchy when analyzed according to a story grammar. In Experiment 1, children free recalled the stories from memory. Overall, performance improved with age of the subject. Like adults, children in all age groups recalled high-level information in the hierarchy better than low-level information. In addition, information central to the story theme was recalled better than tangential supporting details. These results suggested that even young children possess and use knowledge of narrative structures during comprehension. In Experiment 2, children in the three age groups answered questions that required retrieval of specific facts from the stories. Again, performance improved with age and was superior for thematically important facts. The similarity between the free and cued recall results suggests that performance differences were due to different encoding skills rather than to differences in generation or articulation processes. However, developmental differences in encoding ability appear to be independent of knowledge of narrative structure.

82. Faught, W. S. Motivation and intentionality in a computer simulation model of paranoia. Birkhauser, Basel, 1978.

This book describes a computer simulation model of paranoia. The model mimics the behavior of a patient participating in a psychiatric interview by answering questions, introducing its own topics, and responding to negatively-valued (e.g., threatening or shame-producing) situations. The focus of this work is on the motivational mechanisms required to instigate and direct the modeled behavior. The major components of the model are:

(1) A production system (PS) formalism accounting for the instigation and guidance of behavior as a function of internal (affective) and external (real-world) environmental factors. Each rule in the PS is either an action pattern (AP) or an interpretation pattern (IP). Both may have either affect (emotion) conditions, external variables, or outputs of other patterns as their initial conditions (left-hand sides). The PS activates all rules whose left-hand sides are true, selects the one with the highest affect, and performs the action specified by the right-hand side.

(2) A model of affects (emotions) as an anticipation mechanism based on a small number of basic pain-pleasure factors. Primary activation (raising an affect's strength) occurs when the particular condition for the affect is anticipated (e.g., anticipation of pain for the fear affect). Secondary activation occurs when an internal construct (AP, IP, belief) is used and its associated affect is processed.

(3) A formalism for intentional behavior (directed by internal models) requiring a dual representation of symbol and concept. An intentional object (belief) can be accessed either by sensing it in the environment (concept) or by its name (token). Similarly, an intentional action (intention) can be specified either by its conditions in the immediate environment (concept) or by its name (token).

Issues of intelligence, psychopathological modeling, and artificial intelligence programming are discussed. The paranoid phenomenon is found to be explainable as an extremely skewed use of normal processes. Applications of these constructs are found to be useful in AI programs dealing with error recovery, incompletely specified input data, and natural language specification of tasks to perform.

83. Hayes-Roth, B., and Hayes-Roth, R. Cognitive processes in planning. Rand Report R-2366-ONR, 1979.

We propose a model of the planning process. The model assumes that planning comprises the activities of a variety of cognitive "specialists." Each specialist can suggest certain kinds of decisions for incorporation into the plan in progress. A dynamically changing blackboard composed of several planes records planning decisions of different types. These include decisions about: (a) how to approach the planning problem; (b) what knowledge bears on the problems; (c) what kinds of actions to try to plan; (d) what specific actions to plan; and (e) how to allocate cognitive resources during planning. Within each of these categories, different specialists suggest decisions at different levels of abstraction. The activities of the various specialists are not coordinated in any systematic way. Instead, the specialists operate opportunistically, suggesting decisions whenever promising opportunities arise. We present a detailed account of the model and illustrate its assumptions with a "thinking-aloud" protocol. We also contrast the model with earlier models of planning and discuss implications for future research.

84. Hayes-Roth, B., Hayes-Roth, F., Rosenschein, S., and Cammarata, S. Modeling planning as an incremental, opportunistic process. Proceedings of the 6th International Joint Conference on Artificial Intelligence, Tokyo, Japan, 1979. Also issued as Rand Note N-1178-ONR, 1979.

Planning is the process of formulating an intended course of action. In this paper we present a model of planning and describe the current version of an INTERLISP simulation of the model. We also review psychological results which confirm the model's basic assumptions for human planning behavior.

85. Hayes-Roth, F. Syntax, semantics, and pragmatics in speech understanding systems, In W. Lea (Ed.), Trends in speech recognition. Englewood Cliff, N.J.: Prentice-Hall, 1979.

Several kinds of higher-level knowledge can assist us in solving the speech understanding problem. Uncertainties arising from acoustic-phonetic errors and ambiguities can often be resolved by subjecting the conflicting word hypotheses to syntactic, semantic, or pragmatic analyses. Syntactic knowledge enables us to determine whether a particular sequence of hypothesized words can occur within a grammatical sentence. In addition, syntax provides a basis for predicting additional but

unhypothesized fragments of the sentence. Semantic knowledge provides a capability to determine if a syntactically correct sentence is actually meaningful. It may also predict sentence constituents that could relate to current fragments in meaningful ways. Finally, pragmatic knowledge enables us to determine if a meaningful sentence is plausible and appropriate in the context of an ongoing dialogue.

86. Hayes-Roth, F. Distinguishing theories of representation: A critique of Anderson's "Arguments concerning mental imagery." Psychological Review, in press. Also issued as Rand Paper P-6180, 1978.

    In a recent article, Anderson argued that behavioral data could not distinguish alternative theories of memory representations. The theorem Anderson proved does not support his conclusions. Five fallacies in his argument are criticized: (1) Behavioral data cannot distinguish alternative models; (2) An invertible function relates corresponding states of alternative representational theories; (3) Propositional models can account for data supporting image models and, thus, warrant equal credibility; (4) Propositional descriptions constitute parsimonious models; (5) Unless explicitly operationalized, image models cannot support theoretical or empirical research. Contrary to these beliefs, representational differences can qualitatively affect performance, and such important differences apparently characterize the analog class of imagery models.

87. Hayes-Roth, F., Klahr, P., Burge, J., and Mostow, J. Machine methods for acquiring, learning, and applying knowledge. Rand Paper P-6241, 1978.

    Recent advances in intelligent systems have emphasized the use of "expert knowledge" to solve problems. This paper describes a research plan for attacking the core problems impeding the rapid development of such knowledge-based systems. We identify the two chief problems as knowledge programming and learning. The task of knowledge programming is to create an intelligent system that does what an expert says it should. The learning problem requires criticizing and expanding current knowledge to improve system performance. In this view, learning produces new knowledge which must be accommodated to implement an improved system. This accommodation requires a capability for incremental knowledge programming. After describing the motivating problem in detail, we define the technical requirements for supporting system extensibility and improvability. Research proposed to achieve these objectives is

described and related to previous work. Numerous examples are drawn from a heuristic program that plays a moderately difficult card game (Hearts). Several appendices provide additional details on many technical issues, including: the representation of knowledge and the structure of knowledge bases; the design of a knowledge programmer; various control methods, including caching and demons; the design of a learning workbench; an illustrative learning scenario; and various learning heuristics.

88. Hayes-Roth, F., and Wesson, R. Distributed intelligence systems for situation assessment. Proceedings of the Workshop on Distributed Sensor Nets, Carnegie-Mellon University, Pittsburgh, 1978.

The principal features of distributed intelligent (DI) systems include a diversity of perspectives arising from separated individuals and a problem-solving method whereby the individuals can coordinate their activities to accomplish a collective objective. These features require numerous capabilities and supporting structures. A system that embodies such capabilities, however, seems especially well suited to situation assessment (SA) tasks. These tasks require the collection, analysis, and interpretation of widely disparate data. Moreover, comparably complex and distributed systems are often required to disseminate the results of these analyses effectively. In this paper, we explore the relationships among structural capabilities of DI systems and functional requirements of effective SA systems. We discuss some of the options and trade-offs of various architectural decisions in the context of two contrasting DI designs.

89. Hayes-Roth, F., and Wesson, R. Dynamic planning: Searching through time and space. Rand Paper P-6266, 1978.

A new type of planning methodology is introduced. Called "dynamic planning" because of its similarity to the technique of dynamic programming, it creates a plan of actions by simulating the effects of an initial plan and correcting the plan as required. Instead of using a fixed time-step or level of abstraction in the simulation, this technique dynamically changes either or both of these quantities to achieve a high degree of efficiency. Conditions under which these changes should be made are explored in a domain of objects moving through space, and architectures suitable for implementation are suggested.

90. Heiser, J. F., Colby, K. M., Faught, W. S., and Parkison, R. C. Testing Turing's test. Journal of Psychiatric Research, forthcoming.

Turing suggested that passing a conversational test is a necessary and possibly sufficient condition for defining or determining that intelligence has been successfully embodied in a machine. We conducted a Turing's test with an existing computer simulation model of paranoia, modifying the test so that interviewers conversed with a person and a computer model on separate days, as opposed to simultaneously. Five physicians with psychiatric training and experience reached five correct and five incorrect conclusions in deciding whether they were interviewing, by teletype, a paranoid patient or a computer simulation of paranoia. We believe that our modification of Turing's imitation game generates a weak but fair test which has been passed by our model. This is the first report of a formal Turing test which a computer program has passed.

91. Kellogg, C., Klahr, P., and Travis, L. Deductive planning and pathfinding for relational data bases. In H. Gallaire and J. Minker (Eds.), Logic and data bases. New York: Plenum, 1978, 179-200.

Inference planning techniques have been implemented and incorporated within a prototype deductive processor designed to support the extraction of information implied by, but not explicitly included in, the contents of a relationally structured data base. Deductive pathfinding and inference planning are used to select small sets of relevant premises and to construct skeletal derivations. When these "skeletons" are verified, the system uses them as plans to create data-base access strategies that guide the retrieval of data values, to assemble answers to user requests, and to produce proofs supporting those answers. Several examples are presented to illustrate the current capability of the prototype Deductively Augmented Data Management (DADM) system.

92. Klahr, P. Partial proofs and partial answers. Proceedings Fourth Workshop on Automated Deduction, 1979, 115-121. Also issued as Rand Paper P-6239, 1978.

In many cases an automatic deduction system cannot find complete proofs for particular theorems, goals, or questions requiring deductive support. In many cases information needed to complete proofs is missing from the data base. In other cases processing limits may have been reached before proofs could be completed. Rather than disregarding such partial proofs as most systems do,

the DADM system displays them to users and identifies subgoals that remain unresolved. Missing information is given in the form of partial, or conditional, answers. Examples are presented to show the value and importance of such partial proofs and partial answers.

93. Klahr, P. Planning techniques for rule selection in deductive question-answering. In D. A. Waterman and F. Hayes-Roth (Eds.), Pattern-directed inference systems. New York: Academic Press, 1978, 223-239.

Deductive planning techniques are described for rule selection in question-answering systems. Rules typically represent inferential knowledge applicable to a given domain of discourse. Given a question-answering system containing a large number of such rules, a crucial problem arises in selecting those rules that are relevant and needed to answer particular input queries. A planning process has been implemented to find chains of rules that deductively infer the desired conclusions. The processes of forward chaining from assumptions and backward chaining from goals are combined to form middle-term chains, which provide the basis of the planning mechanism. The applicability and generality of these techniques for use in other rule-based systems is also discussed.

94. Lenat, D. B., Hayes-Roth, F., and Klahr, P. Cognitive economy in artificial intelligence systems. Proceedings of the 6th International Joint Conference on Artificial Intelligence, Tokyo, Japan, 1979.

Intelligent systems can explore only tiny subsets of their potential external and conceptual worlds. To increase their effective capacities, they must develop efficient forms of representation, access, and operation. In this paper we develop several techniques which do not sacrifice expressibility, yet enable programs to (semi-)automatically improve themselves and thus increase their productivity. The basic source of power is the ability to predict the way that the program will be used in the future, and to tailor the program to expedite such uses. Abstraction, caching, and expectation-simplified processing are principal examples of such techniques. We discuss the use of these and other economic principles for modern AI systems. Our analysis leads to some counterintuitive ideas and proposed policies which are not generally followed because their contribution to overall cognitive utility is not readily apparent. For example, we challenge the typical practice of storing properties "economically" in hierarchical inheritance nets. That non-redundant storage practice provides some

storage cost savings, but significantly increases processing costs. As an alternative, we suggest storage schemes to improve performance by exploiting various forms of redundancy consistent with general caching heuristics.

95. Mostow, J., and Hayes-Roth, F. Operationalizing heuristics: Some AI methods for assisting AI programming. Proceedings of the 6th International Joint Conference on Artificial Intelligence, Tokyo, Japan, 1979.

Machine-aided heuristic programming is advocated as a paradigm for incorporating domain knowledge in intelligent task performance programs. In this paradigm, a system interactively assimilates a natural language description of a task, advice on how to perform it, and definitions of the domain concepts in terms of which the advice is expressed. The system translates this input into an internal representation, operationalizes the assimilated knowledge to make it effective, integrates different pieces of advice, and applies them to the performance of the task. Important problems of this paradigm are defined and approaches for their solution are suggested. Some desiderata for the internal knowledge representation are proposed and a typed applicative LISP-like language appearing to satisfy them is described. Operationalization is defined in terms of transforming well-defined but non-effective expressions into effectively executable ones. Several techniques for performing these processes mechanically are presented and applied to an example drawn from the domain of the card game Hearts. This paper focuses on the design of a system to operationalize heuristics for the game of Hearts.

96. Mostow, J., and Hayes-Roth, F. Machine-aided heuristic programming: A paradigm for knowledge engineering. Rand Note N-1007, 1979.

Machine-aided heuristic programming is advocated as a paradigm for incorporating domain knowledge in intelligent task performance programs. In this paradigm, a system interactively assimilates a natural language description of a task, advice on how to perform it, and definitions of the domain concepts in terms of which the advice is expressed. The system translates this input into an internal representation, operationalizes the assimilated knowledge to make it effective, integrates different pieces of advice, and applies them to the performance of the task. Important problems of this paradigm are defined and approaches for their solution are suggested. Some desiderata for the internal

knowledge representation are proposed and a typed applicative LISP-like language appearing to satisfy them is described. Operationalization is defined in terms of transforming well-defined but non-effective expressions into effectively executable ones. A Hearsay-II-blackboard-like mechanism for dynamically integrating different pieces of advice is described. Several techniques for performing these processes mechanically are presented and applied to an example drawn from the domain of the card game Hearts. A system to accept and use Hearts advice is currently being implemented as an instantiation of the advocated paradigm.

97. Thorndyke, P. Heuristics for human knowledge acquisition from maps. Proceedings of the 6th International Joint Conference on Artificial Intelligence, Tokyo, Japan, 1979. Also issued as Rand Note N-1193-ONR.

    Acquiring knowledge from a map depends upon a variety of processes for focusing attention, encoding information, and integrating knowledge of various types. This paper describes the heuristics people use to study and learn maps. Verbal protocols were obtained from three expert map users and five novice map users attempting to learn a map. Analysis of the learning protocols suggested four categories of processes that were invoked during learning: attention, encoding, evaluation, and control. The subjects showed large variations in success at learning the map and in the learning heuristics they used. Analyses of the performance and strategy data revealed that the use of certain heuristics in each category, particularly those used for encoding spatial information, was most predictive of learning success. In addition, good learners differed from poor learners in their ability to evaluate their learning progress and to focus their attention in accordance with a learning plan. A comparison of the performance of map-using experts and novices suggested that success in learning depended on the use of powerful heuristics and not on prior map-using expertise.

98. Thorndyke, P., and Stasz, C. Individual differences in knowledge acquisition from maps. Rand Report R-2375-ONR, 1979.

    This study investigated the strategies subjects use to acquire knowledge from maps. On each of a series of learning trials, three expert map users and five novice map users studied a map and provided verbal protocols of their study behavior. Analysis of the learning protocols suggested four categories of processes that were invoked during learning: attention, encoding, evaluation, and

control. Large individual differences in both performance and strategy usage were observed in this task. Analyses of the performance and strategy data revealed that the use of certain strategies in each category, particularly those used for encoding spatial information, was most predictive of learning performance. In addition, good learners differed from poor learners in their ability to evaluate their learning progress and to focus their attention on unlearned information. An analysis of the performance of map-using experts suggested that success in learning depended on strategies and not on familiarity with the task domain or materials. The implications of these results for training expertise in map learning are discussed.

99. Thorndyke, P., and Stasz, C. Strategies for map learning. Paper presented at the American Educational Research Association meetings, 1979. Rand Paper P-6311.

Acquiring knowledge from a map depends upon a variety of processes for focusing attention, encoding information, and integrating knowledge of various types. This paper describes the heuristics people use to study and learn maps. Verbal protocols were obtained from three expert map users and five novice map users attempting to learn a map. Analysis of the learning protocols suggested four categories of processes that were invoked during learning: attention, encoding, evaluation, and control. The subjects showed large variations in success at learning the map and in the learning heuristics they used. Analyses of the performance and strategy data revealed that the use of certain heuristics in each category, particularly those used for encoding spatial information, was most predictive of learning success. In addition, good learners differed from poor learners in their ability to evaluate their learning progress and to focus their attention in accordance with a learning plan. A comparison of the performance of map-using experts and novices suggested that success in learning depended on the use of powerful heuristics and not on prior map-using expertise.

100. Thorndyke, P., and Yekovich, F. A critique of schemata as a theory of human story memory. Poetics, 1979, in press. Also issued as Rand Paper P-6307, 1979.

The concept of a "schema" as a theoretical construct has regained prominence among memory researchers, particularly those studying prose learning. A schema is a cluster of knowledge that describes the typical properties of the concept it represents. Recent theories built upon the notion of schemata have explained numerous

results in human comprehension, recall, and summarization of prose. While schema theory provides a plausible and descriptive framework for understanding human knowledge processing, it is ill-constrained and provides few detailed process assumptions. This lack of constraint allows sufficient flexibility to accommodate post hoc many empirical results. However, because of this flexibility, the theory is of limited predictive value and is not testable as a scientific theory in its current form. We detail the strengths and weaknesses of schema theory, affirm its promise as a theory of human memory, and suggest areas for future theoretical development.

101. Waterman, D. A., Anderson, R. H., Hayes-Roth, F., Klahr, P., Martins, G., and Rosenschein, S. Design of a rule-oriented system for implementing expertise. Rand Note N-1158-ARPA, 1979.

This note describes the preliminary design of a Rule-Oriented System for Implementing Expertise (ROSIE). This system will serve as a tool for model builders seeking to apply expert knowledge to the analysis of problems and the evaluation of solutions in complex domains, especially domains for which useful analytic models are unavailable. Models built within the ROSIE system constitute simulations in the application domain. Control in these models is data-directed. That is, actions are specified by sets of rules having the basic form: "IF [conditions] THEN [actions]." The actions are executed when data matching the conditions appear in the model's data base. Major features of ROSIE include: hierarchic structures on data elements and rules, user selection of rule-invocation strategies, user control of rule iteration, user control of rule and data activation, and sophisticated user support tools.

RESEARCH IN COGNITIVE SCIENCE BY RAND STAFF: 1975-1978

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11. Faught, W. S., Colby, K. M., and Parkison, R. C. Inferences, affects, and intentions in a model of paranoia. Cognitive Psychology, 1977, 9, 153-187.

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17. Hayes-Roth, B., and Hayes-Roth, F. Plasticity in memorial networks. Journal of Verbal Learning and Verbal Behavior, 1975, 14, 506-522.

18. Hayes-Roth, B., and Hayes-Roth, F. A comparative psychological investigation of pattern classification theories. Proceedings of the Third International Joint Conference on Pattern Recognition, Coronado, California, 1976.

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33. Hayes-Roth, F., Fox, M., Gill, G., and Mostow, D. J. Semantics and pragmatics in the Hearsay-II speech understanding system. Speech Understanding Systems: Summary of Results of the Five-Year Research Effort, Department of Computer Science, Carnegie-Mellon University, 1976.

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